Dynamics of co-occurring frog species in three ponds utilized by the endangered Green and Golden Bell Frog *Litoria aurea*

Graham H. Pyke[1] **and Arthur W. White**[2]
[1]Australian Museum, 6 College Street, Sydney, New South Wales 2000
[2]Biosphere Environmental Consultants, 69 Bestic Street, Rockdale, New South Wales 2216

ABSTRACT

Populations of five frog species were monitored at three ponds utilized by the endangered Green and Golden Bell Frog *Litoria aurea* over a three year period 1993–1996. *Litoria aurea* bred at the two semi-permanent ponds with fluctuating water levels but did not breed at the permanent pond with a relatively constant water level, though it was abundant there. Other frog species generally bred at all ponds where they were found. At the semi-permanent ponds the numbers of the various frog species fluctuated, but there were no apparent long-term trends. On the other hand, at the permanent pond there were changes through time in both plant and frog species. As the pond aged, the relative abundance of various species of emergent aquatic plants changed, the area of open water steadily decreased, and the depth decreased. Over the same period, the relative abundance of several frog species changed with the most abundant species being first *L. aurea* and then *Limnodynastes peronii*, and finally *Crinia signifera* increased to become co-dominant with *Lim. peronii*. The temporal changes in the numbers of each species were attributed to the changes in the condition of the ponds.

Key words: Frog, Endangered, Abundance, Community.

INTRODUCTION

The aims of our study were to use the results from a monitoring programme, that focused on the endangered Green and Golden Bell Frog *Litoria aurea*, to assess year-to-year changes in relative population levels of all frog species in and around several ponds utilized by this species, and to relate any changes to observed changes in these ponds.

Many water bodies show year-to-year changes. Their associated plant communities show similar changes, especially in relation to variation in soil moisture levels. These habitats are likely to change over the years in terms of their suitability for different frog species. Hence, many frog communities may show year-to-year changes in the relative abundance of each species. There have been relatively few studies of year-to-year changes in the relative abundances of different species in frog communities despite the likely need for long-term studies of frog abundance to distinguish between natural fluctuations and declines with anthropogenic causes (Pechman *et al.* 1991; Bebee 1996). A number of studies have, however, examined differences among frog species in the timing of breeding and the periods during which tadpoles are present, and have generally found that different frog species tend to use the same water body at different times during the year (e.g., Dixon and Heyer 1968; Heyer 1976; Wiest 1982).

Most studies of Australian frog communities have been relatively brief and have provided little information concerning year-to-year changes. The longest published study, carried out over a 38 month period, included four breeding seasons of the frogs involved (White 1993). Other Australian studies have generally spanned one or two breeding seasons (e.g., Humphries 1979; Odendaal 1981; Lemckert 1991) and have rarely extended to three breeding seasons (e.g., Dankers 1977). Overseas studies have also been generally restricted to a single season (e.g., Dixon and Heyer 1968; Heyer 1976; Wiest 1982). The present study has extended over three years, thus providing an opportunity to consider year-to-year changes in a community of frog species.

The Green and Golden Bell Frog *Litoria aurea* is listed as an endangered frog species in New South Wales (Schedule 1 of the New South Wales *Threatened Species Conservation Act 1995*) and has been the subject of considerable recent scientific interest (e.g., Murphy 1996; Pyke and Osborne 1996; van de Mortel and Goldingay 1998; van de Mortel and Buttemer 1998; van de Mortel *et al.*, in press). In an earlier study we attempted to derive a detailed description of the habitat characteristics of *L. aurea* breeding sites (Pyke and White 1996). We found, in particular, that, in order to breed successfully, this species is apparently best served by water bodies that are either ephemeral or fluctuate significantly in water

level (Pyke and White 1996). Monitoring *L. aurea* at a variety of sites can help to review this proposition.

A programme of monitoring *L. aurea* at Homebush Bay, a suburb of Sydney, has been in operation since late 1993. It was established as part of actual and proposed development in this area in association with preparations for the Sydney Olympics in the year 2000 (Greer 1994; Pyke 1995). Though not designed specifically to provide information about year-to-year changes in relative abundance of frog species or to further evaluate the habitat requirements of *L. aurea*, this programme has none-the-less resulted in information relevant to both these goals.

METHODS

Location and duration of study

This study, carried out at Homebush Bay within the general area being developed in association with the Sydney Olympics (Greer 1994; Homebush Bay Corporation 1994; Pyke 1995), was located about 12 km west of the Sydney Harbour Bridge and in an area surrounded by industrial and highly urbanized parts of Sydney (Pyke 1995).

Three artificially-created ponds were surveyed. The "Golf Pond" was about 20 m north of Bannon's bridge where the State Sports Centre access road crosses Boundary Creek. A golf driving range has been established on the northern side of this pond (Fig. 1; see also Pyke 1995). The "Lake Domis Pond" was located just east of the northern end of Figtree Drive (Fig. 1; see also Pyke 1995). The "Manure Pond" was located just north of a paved area with painted Olympic Games symbol (Fig. 1; see also Pyke 1995). The characteristics and history of each pond are discussed below. Distances between the ponds range from 200 m to 600 m, while distances of the ponds from a disused 16 ha quarry known as the State Brickpit range from 140 m to 720 m (Fig. 1).

The study began in November 1993 when the Golf Pond was first surveyed for frogs and continued until September 1996. The ponds were regularly surveyed with 47 surveys for the Golf Pond, 49 for Lake Domis Pond and 42 for the Manure Pond. The frequency of visits to the ponds ranged from every 1–2 weeks at the Golf Pond to every 2–4 weeks at the other two ponds.

Distribution of L. aurea *within the Homebush Bay area*

At the time of this study, the only self-supporting population of *L. aurea* within the Homebush Bay area is believed to have been that which occurs inside the 16 ha excavated pit in the ground, known as the brickpit (Greer 1994; Pyke 1995; Fig. 1). This population apparently acted as a source of individuals of this species which disperse widely, especially during wet weather. The species was found at all three ponds considered in this study (see below). The species is now found and breeds at a number of recently created ponds outside the brickpit (G. Muir, pers. comm).

Characteristics and history of each pond

At the time of this study, the Golf Pond was permanent, while Lake Domis and the Manure Pond were semi-permanent with significantly fluctuating water levels (Fig. 2). The Golf Pond was roughly rectangular, measured about 60 m by 15 m with little variation in outline, and was created in November 1993 to retain water runoff from adjacent areas of grass associated with a Golf Driving Range. Its underlying base consists of compacted clay. By December 1993 it had become a permanent pond with a constant water level set by the height of a water overflow pipe and maximum water depth about 120 cm. During the first three months after its establishment it received plantings of *Juncus* sp. and *Schoenoplectus* sp. After that no planting occurred within or adjacent to the pond, but some plant species did colonize naturally (Fig. 3). Ten wooden boards, measuring 90 cm × 90 cm, were placed around the pond in 1993 as possible shelter sites for frogs (Greer 1994).These boards were placed on low bricks (about 3 cm high) and were about half in the shallow water of the pond and half on the adjacent dry land. Frogs that sheltered beneath them were relatively easy to monitor (see below).

Lake Domis Pond was created in 1992 when the buildings and cattle yards of the former Homebush State Abattoir (Country Meat Sales area) were demolished and the site was levelled. Though not intended as a water collecting site, it acted as the end-point for local surface run-off and resulted initially in the accumulation of a large area of water. A surface drainage system was installed in

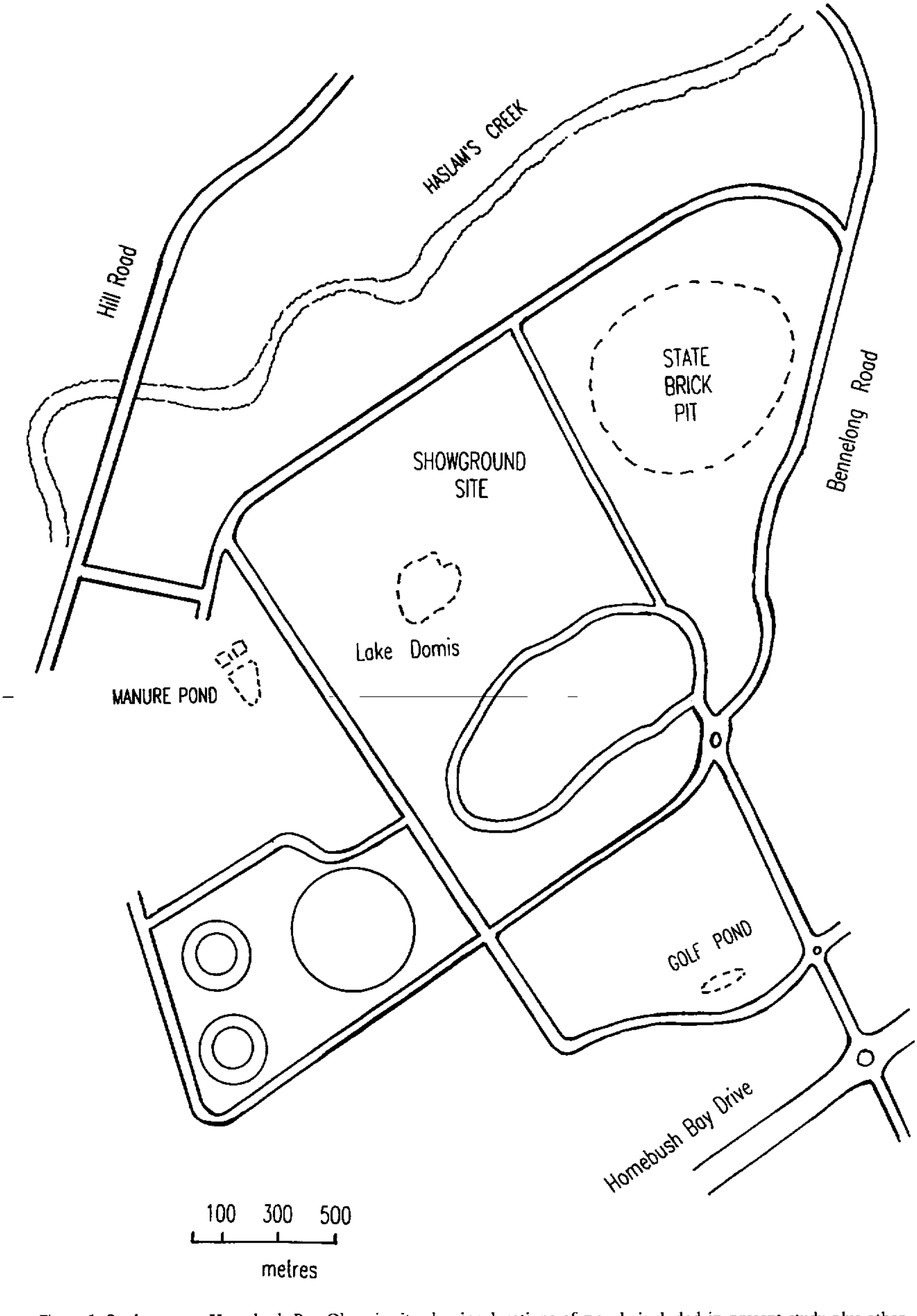

Figure 1. Study area at Homebush Bay Olympic site showing locations of ponds included in present study plus other nearby landmarks.

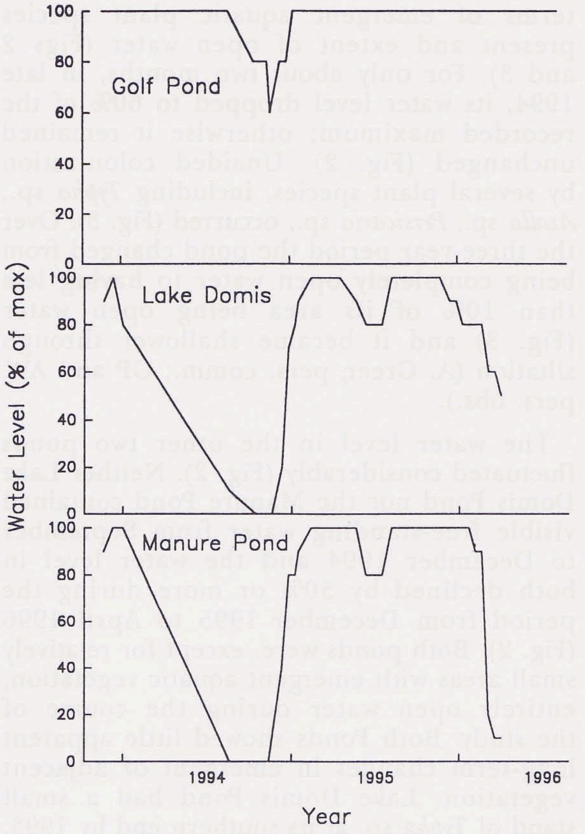

Figure 2. Changes in water level relative to recorded maxima at Golf Pond, Lake Domis Pond and Manure Pond between November 1993 and March 1996. Here any changes in substrate height are not included.

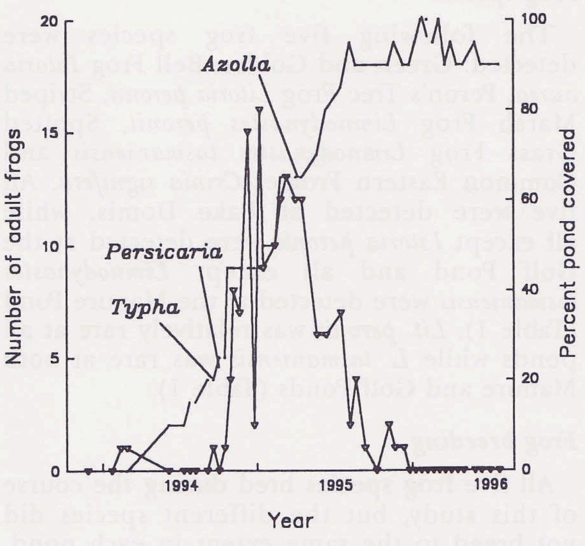

Figure 3. Changes in the number of adult *Litoria aurea* (open triangles) and the percentage of water covered by aquatic plants (continuous line) in the Golf Pond between December 1993 and September 1996. Also depicted are the dates when the pond was first colonized by *Typha* sp., *Persicaria* sp. and *Azolla* sp.

1993 so that, after heavy rain, Lake Domis formed a broad, shallow pond, with depth mostly less than 10 cm, maximum depth about 40 cm, and reaching up to 65 m by 45 m in dimensions after heavy rain, but with considerable variation in outline. It was a semi-permanent pond, drying up completely after several months without sufficient rainfall. Its underlying base consisted of crushed bricks and building rubble with some silt and sand.

Manure Pond originally received water and cattle manure when a large paved cattle sales yard was either washed out or received rain. After the sales yard and most associated buildings were demolished (prior to 1990), Manure Pond remained as a scoured out, rectangular basin about 40 m × 20 m, plus two remaining concrete manure pits of the old abattoir, adjacent to the basin at its southern end. Manure Pond subsequently collected water from a large paved area which also remained in the adjacent area. Though this pond occasionally dried up almost completely, it was also relatively deep at times with a general depth ranging from 1 to 2 metres. It varied little in outline. The underlying base of the pond was relatively flat and, excluding the associated concrete pits, was mostly composed of clay, with some concrete rubble at one end.

Both Lake Domis Pond and Manure Pond were removed early in 1996 ater the creation of replacement habitat elsewhere on site. The Golf Pond dried out in April 1997.

During the course of this study, the nature of the areas adjacent to these ponds changed little. Uphill from Golf Pond was an extensive area of mown grass associated with the golf driving range. Downhill was a narrow strip of grass, which ended with the channel of Boundary Creek. There were few nearby shrubs or trees. The area surrounding Lake Domis Pond consisted of building rubble covered with various sedges, grasses and weeds, including *Cyperus* sp., *Eragrostis* sp., *Verbena* sp., *Digitaria* sp., *Medicago arabica* and *M. truncata*. As the pond expanded after rain part of this area was flooded. About 50 m from this pond there was a small stand of shrubs and trees, consisting mostly of *Melaleuca* sp. and *Acacia* sp.; otherwise the area around the pond had few shrubs and trees. The area around Manure Pond consisted of building rubble with a covering primarily

of *Pennisetum* sp. and *Verbena* sp. Except for a tree-lined embankment about 30 m from this pond, the area around it had few shrubs or trees.

Monitoring methods

Monitoring the frogs was carried out during the day and at night recording any frog calls detected by ear and using searches of each pond and its adjacent area in all places considered likely to harbour eggs, tadpoles, sheltering frogs (including wooden shelter sites), or basking or calling frogs. Tadpoles were surveyed by passing a small net through pond areas where they could occur. Most observations were made by one of us (AW) but we have also included some observations made by others, and reported in Pyke (1995) as well as previously unpublished records by A. Greer (1997, pers. comm.). Frogs were counted but not marked. By noting the locations of any frogs detected, we attempted to avoid counting the same individual frog more than once during the same visit to a pond. The age class of any observed *L. aurea* individual was recorded as tadpole, immature (i.e., less than 40 mm snout-vent length), or adult. For each visit, we recorded the total numbers detected of each age class for each frog species.

During each visit we also recorded the dominant plant species present in and within 10 m of the pond; proportion of open water present (based on visual estimate) and water level (using measuring sticks permanently imbedded in the bottom of each pond at the deepest point). Substrate height relative to each of these measuring sticks was recorded when they were first put into place and subsequent estimates of water depth assumed that this substrate height did not change. We considered that breeding had occurred in a particular pond if either spawn or tadpoles were found, and did not regard calling or the presence of immature frogs, on their own, as demonstrations of breeding. Movements of several hundred metres between ponds have been recorded for immatures of this species (Pyke and White, unpubl.). Male *L. aurea* may sometimes call at ponds where spawn or tadpoles are never found (White, pers. obs.). In the present study, however, calling was always associated with the presence of eggs and/or tadpoles.

RESULTS

Temporal changes in pond properties

During the course of the study the Golf Pond was permanent with a relatively constant water level, but it changed considerably in terms of emergent aquatic plant species present and extent of open water (Figs 2 and 3). For only about two months, in late 1994, its water level dropped to 60% of the recorded maximum; otherwise it remained unchanged (Fig. 2). Unaided colonization by several plant species, including *Typha* sp., *Azolla* sp., *Persicaria* sp., occurred (Fig. 3). Over the three-year period the pond changed from being completely open water to having less than 10% of its area being open water (Fig. 3) and it became shallower through siltation (A. Greer, pers. comm.; GP and AW, pers. obs.).

The water level in the other two ponds fluctuated considerably (Fig. 2). Neither Lake Domis Pond nor the Manure Pond contained visible free-standing water from September to December 1994 and the water level in both declined by 50% or more during the period from December 1995 to April 1996 (Fig. 2). Both ponds were, except for relatively small areas with emergent aquatic vegetation, entirely open water during the course of the study. Both Ponds showed little apparent long-term changes in emergent or adjacent vegetation. Lake Domis Pond had a small stand of *Typha* sp. at its southern end by 1993, and in 1995 a smaller additional western stand had begun to form. There were no other emergent aquatic plants in the pond. The Manure Pond supported a dense stand of *Typha* sp. in its deepest part, but contained little other emergent aquatic vegetation. A small stand of *Cyperus* sp. developed during the summer of 1995/96.

Frog species

The following five frog species were detected: Green and Golden Bell Frog *Litoria aurea*, Peron's Tree Frog *Litoria peronii*, Striped Marsh Frog *Limnodynastes peronii*, Spotted Grass Frog *Limnodynastes tasmaniensis* and Common Eastern Froglet *Crinia signifera*. All five were detected at Lake Domis, while all except *Litoria peronii* were detected at the Golf Pond and all except *Limnodynastes tasmaniensis* were detected at the Manure Pond (Table 1). *Lit. peronii* was relatively rare at all ponds while *L. tasmaniensis* was rare at both Manure and Golf Ponds (Table 1).

Frog breeding

All five frog species bred during the course of this study, but the different species did not breed to the same extent in each pond. *Litoria aurea* showed no sign of breeding in the Golf Pond despite being present there during February 1994 and over the period from October 1994 to December 1995 (Figs 4 and 5 and Table 2). It did, however, breed at

Table 1. Total numbers of frogs recorded at each pond during study period i.e., from November 1993 to September 1996.

Frog\Pond	Lake Domis	Manure Pond	Golf Pond
Litoria aurea	adults: 72 immatures: 103	adults: 35 immatures: 27	adults: 138 immatures: 16
Limnodynastes peronii	194	102[1]	295
Limnodynastes tasmaniensis	77	—	3
Litoria peronii	13	9[1]	—
Crinia signifera	315	38[1]	156
Total number of counts	49	42	48

Notes: 1. At the Manure Pond species other than *L. aurea* were counted for 18 of the 42 total number of counts.

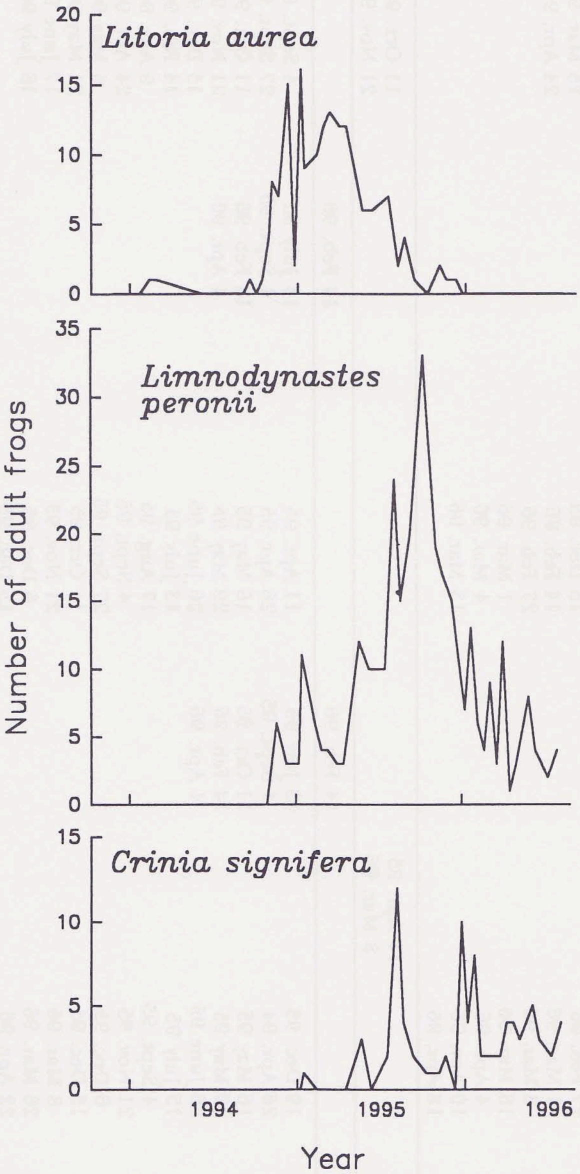

Figure 4. Numbers of *Litoria aurea*, *Lim. peronii* and *Crinia signifera* at Golf Pond between November 1993 and September 1996.

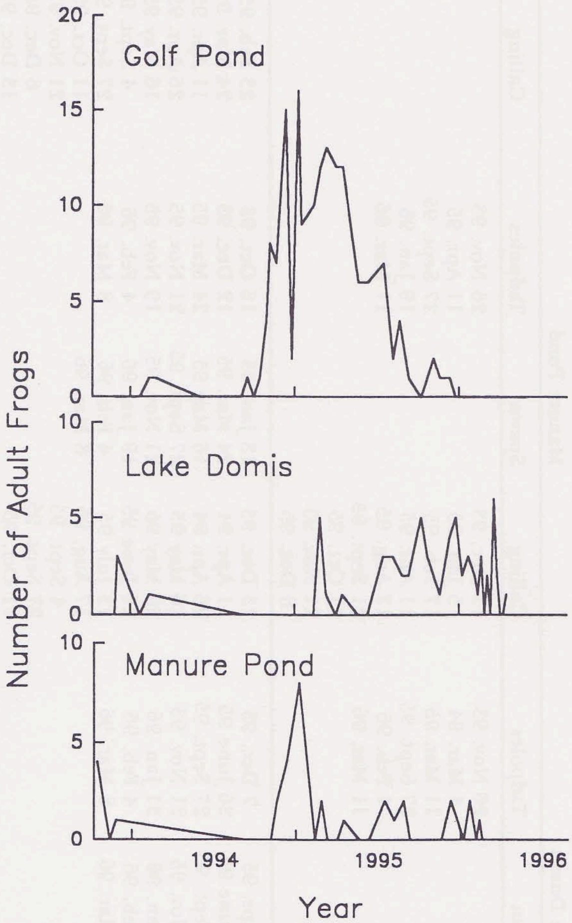

Figure 5. Numbers of adult *Litoria aurea* at the three study ponds between November 1993 and March 1996.

the other two ponds (Table 2). *Limnodynastes peronii* and *C. signifera*, on the other hand, bred at all three ponds, while *L. tasmaniensis* and *Lit. peronii* were recorded as having bred at one or two of the ponds (Table 2).

Frog populations

At Golf Pond each frog species showed a different temporal pattern in terms of its numbers (see Fig. 4). For about the first 18 months *L. aurea* was the most commonly encountered frog (Fig. 4). However, after reaching peak numbers between January and March 1995, this species declined considerably and was no longer found after January 1996 (Fig. 4). *Lim. peronii* was not recorded before November 1994, almost a year after the creation of the pond, then increased rapidly to reach peak numbers in November 1995. It then decreased to much

Table 2. Breeding records for frogs during study period.

Frog\Pond	Lake Domis			Manure Pond			Golf Pond		
Calling\Spawn\Tadpoles	Calling	Spawn	Tadpoles	Calling	Spawn	Tadpoles	Calling	Spawn	Tadpoles
Litoria aurea	11 Apr. 95 17 Aug. 95 4 Sept. 95 27 Sept. 95 11 Oct. 95 6 Dec. 95 11 Jan. 96 19 Jan. 96 14 Feb. 96		26 Nov. 93 4 Mar. 94 11 Mar. 95 27 Sept. 95 4 Feb. 96 11 Mar. 96	13 Dec. 93 15 Jan. 95 17 Feb. 95 11 Apr. 95 17 Aug. 95 21 Sept. 95 11 Oct. 95 21 Nov. 95 6 Dec. 95		26 Nov. 93 11 Apr. 95 27 Sept. 95 19 Jan. 95 11 Mar. 96			
Limnodynastes peronii	12 Dec. 93 19 Dec. 93 4 Mar. 94 11 Apr. 94 26 Apr. 95 16 May 95 29 May 95 21 Nov. 95 6 Dec. 95 15 Dec. 95 11 Jan. 96 31 Jan. 96 14 Feb. 96 27 Feb. 96 1 Mar. 96 8 Mar. 96 18 Mar. 96 4 Apr. 96 10 Apr. 96 18 Apr. 96	11 Apr. 95 26 June 95 27 Sept. 95 21 Nov. 95 31 Jan. 96 4 Feb. 96 8 Mar. 96	7 Dec. 93 26 June 95 27 Sept. 95 21 Nov. 95 31 Jan. 96 4 Feb. 96 8 Mar. 96	13 Dec. 93 11 Apr. 94 26 Apr. 94 16 May 95 29 May 95 26 June 95 13 July 95 17 Aug. 95 4 Sept. 95 27 Sept. 95 11 Oct. 95 21 Nov. 95 6 Dec. 95 15 Dec. 95 14 Feb. 96 27 Feb. 96 1 Mar. 96 4 Mar. 96 13 Mar. 96	13 Jan. 95 24 Mar. 95 16 May 95 27 Sept. 95 21 Nov. 95 19 Jan. 96 4 Feb. 96 8 Mar. 96	16 Oct. 93 12 Dec. 93 24 Mar. 95 21 Nov. 95 19 Nov. 95 4 Feb. 96 8 Mar. 96	23 Feb. 95 24 Mar. 95 11 Apr. 95 26 Apr. 95 16 May 95 4 Sept. 95 27 Sept. 95 11 Oct. 95 21 Nov. 95 6 Dec. 95 15 Dec. 95 14 Feb. 96 28 Feb. 96 25 Mar. 96 24 Apr. 96	11 Mar. 94 17 Feb. 95 24 Mar. 95 26 Apr. 95 29 May 95 4 Sept. 95 21 Nov. 95 11 Jan. 95 14 Feb. 96 24 Apr. 96	14 Nov. 94 24 Mar. 95 26 Apr. 95 29 May 95 21 Nov. 95 11 Jan. 96 14 Feb. 96 24 Apr. 96
Limnodynastes tasmaniensis		11 Apr. 95 8 Mar. 96					11 Oct. 95 21 Nov. 95		
Litoria peronii			14 Feb. 96			14 Feb. 96			
Crinia signifera	19 Dec. 93 26 Apr. 94 16 May 95 29 May 95 26 June 95 13 July 95 4 Sept. 95 21 Nov. 95 6 Dec. 95 15 Dec. 95 8 Mar. 96 26 Mar. 96 22 Apr. 96 26 Apr. 96		13 July 95 4 Sept. 95 11 Oct. 95 14 Feb. 96 4 Apr. 96	11 Apr. 95 26 Apr. 95 16 May 95 29 May 95 26 June 95 13 July 95 17 Aug. 95 4 Sept. 95 27 Sept. 95 11 Oct. 95 21 Nov. 95 6 Dec. 95 15 Dec. 95 1 Mar. 96 13 Mar. 96		13 July 95 4 Sept. 95 14 Feb. 96 4 Apr. 96	4 Sept. 95 27 Sept. 95 11 Oct. 95 21 Nov. 95 15 Dec. 95 14 Feb. 96 9 Apr. 96 24 Apr. 96 6 May 96 21 May 96 17 June 96 18 July 96		14 Feb. 95 26 Apr. 95

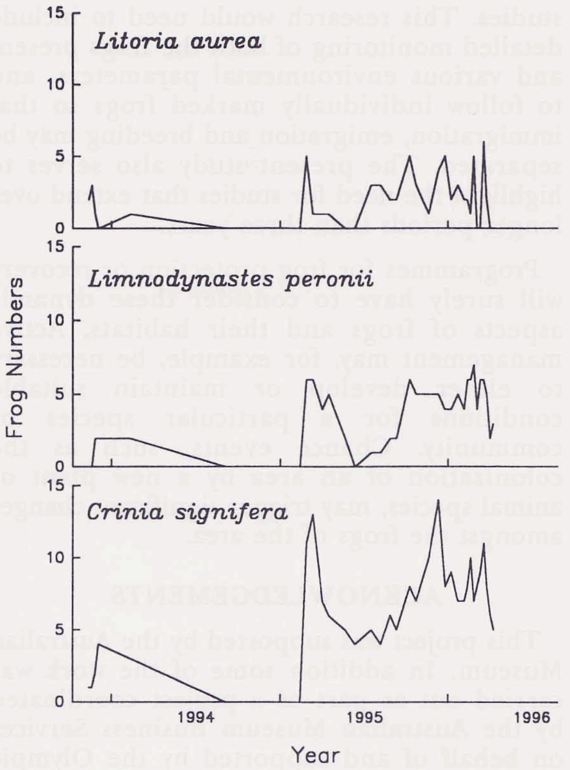

Figure 6. Numbers of *Litoria aurea, Lim. peronii* and *Crinia signifera* at Lake Domis Pond between November 1993 and March 1996.

lower numbers (Fig. 4). Only one individual of *C. signifera* was detected before February 1995 (i.e., during the first 18 months after the pond was created). After that its numbers fluctuated widely (Fig. 4). Since January 1996 it was recorded in similar numbers to *Lim. peronii* (mean numbers detected from January to September 1996 were 6.7 for *Lim. peronii* — n = 15; sd = 4.3 — and 5.2 for *C. signifera* — n = 15, sd = 3.8; P > 0.05, Student-t Test) (Fig. 4). *L. tasmaniensis* remained rare at this pond throughout this study (Table 1). As a result of these differences among the frog species in terms of changes in numbers over time, the relative abundance of each species at Golf Pond changed during the course of the study (Fig. 4). The frog community here was dominated first by *L. aurea*, and then by *Lim. peronii*, and then jointly by the latter species and *C. signifera* (Fig. 4).

The numbers of frogs varied at the other ponds but there was no clear pattern over the three-year period. At Lake Domis Pond, frogs were detected only when standing water was present, the most common frog species was *C. signifera*, and the three dominant species fluctuated in abundance (Fig. 6). At Manure Pond, most of the frogs were either *L. aurea* or *Lim. peronii* (Table 1), and neither showed any trend in numbers.

DISCUSSION

Litoria aurea did not breed at the permanent Golf Pond with its non-fluctuating water level but it did breed at the nearby Lake Domis and Manure Ponds which were semi-permanent ponds with fluctuating water levels. This is consistent with the view of *L. aurea* habitat as previously determined by Pyke and White (1996). It is unknown, however, what the underlying reasons are for this. By comparison, *Lim. peronii* and *C. signifera* were found breeding in both permanent and semi-permanent ponds. Because of the small number of ponds in the present study, it cannot provide a general test of our habitat predictions for *L. aurea*. Such a test will require a comparison of a larger number of ponds of each kind. Such a replicated approach was not possible in the present study.

The plants and frogs at Golf Pond changed during the three-year course of this study. The diversity of aquatic plants increased, the overall abundance of aquatic plants increased, the area of open water decreased, and the pond became shallower. There may also have been concurrent changes in the chemical composition and quantity of water flowing into the pond. The frog community changed with first *L. aurea* increasing in numbers to a peak and then declining. This was followed by a similar increase and decline in *Lim. peronii*. Later *C. signifera* had increased in abundance to similar levels as *Lim. peronii*.

The temporal changes in the abundance of *L. aurea* at the Golf Pond were probably due to changes in its suitability for this species, rather than to population changes occurring throughout the study area for some other reasons. If this had occurred, similar temporal changes in abundance of *L. aurea* would have occurred at the other ponds. This was not the case, as the temporal patterns of abundance of the species at the three study ponds did not correspond (Fig. 5). Since November 1995 the number of *L. aurea* found at the Golf Pond was low or zero, but during this period significant numbers of this species were detected in the vicinity of Lake Domis, the Manure Pond (see Figs 4 and 6) and at other nearby sites (AW, pers. obs.).

The increases and decreases in abundance of the other frog species at Golf Pond probably reflect similar changes in its suitability for maintenance and/or breeding of these species. The colonization dates for *Lim. peronii* and *C. signifera* at the Golf Pond probably reflect its increasing suitability for these species, rather than random times before individuals of these species happened to arrive

at the pond, as both species are common around other nearby water bodies and are known to disperse widely during wet weather (AW, pers. obs.). Likewise the decrease in abundance of *Lim. peronii* at the Golf Pond most probably reflects a decline in suitability of the pond and associated habitats for this species, as the species was, by this time, breeding within the pond.

The underlying reasons for the above temporal patterns in the frog communities at the three ponds are unknown. It is possible that, associated with the changes in the plant community at Golf Pond, are changes in the nature and extent of food suitable for tadpoles. It is also possible that the chemical composition of the water and/or the supply of tadpole food are affected by the presence of certain frog species and that this affects the suitability of the pond for other species. However, while this might explain the decrease in abundance of *L. aurea,* which began after the numbers of *Lim. peronii* had reached relatively high levels, it does not provide a satisfactory explanation for the absence of breeding by *L. aurea,* which was the case despite initially very low numbers of any other frog species. Interactions between the different frog species may also be important.

The relative numbers of the four detected frog species besides *L. aurea,* across the three ponds reflects their known general habitat requirements. *Litoria peronii* is the most arboreal of the species, is often found well above the ground and is rarely found on the ground (Barker *et al.* 1995; White and Pyke, pers. obs.). Its overall rareness reflects the general absence of shrubs and trees around the three ponds, while its presence at Lake Domis and Manure ponds reflects the nearby presence of small areas of shrubs and trees. Of the remaining four species, which all live mostly on the ground or in the water, *L. tasmaniensis* may have the narrowest habitat requirements. It generally breeds in flooded grassy areas and shelters under nearby rocks or timber (Barker *et al.* 1995). Such conditions occurred to some extent at Lake Domis, where this species was most commonly recorded, but not at the other two ponds, where it was rare or absent. The other two species are very widespread and occur in many different habitats (Barker *et al.* 1995; White and Pyke, pers. obs.). They are similarly widespread across our study area.

The present study indicates that frog communities and their habitats show year-to-year changes. However, further knowledge and understanding of these temporal patterns and the reasons for them will require additional studies. This research would need to include detailed monitoring of both the frogs present and various environmental parameters, and to follow individually marked frogs so that immigration, emigration and breeding may be separated. The present study also serves to highlight the need for studies that extend over longer periods than three years.

Programmes for frog protection or recovery will surely have to consider these dynamic aspects of frogs and their habitats. Active management may, for example, be necessary to either develop or maintain suitable conditions for a particular species or community. Chance events, such as the colonization of an area by a new plant or animal species, may trigger significant changes amongst the frogs of the area.

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REFERENCES

Barker, J., Grigg, G. and Tyler, M., 1995. *A Field Guide to Australian Frogs*. Surrey Beatty & Sons: Chipping Norton. 407 Pp.

Beebee, T. J. C., 1996. *Ecology and Conservation of Amphibians*. Chapman and Hall: London.

Dankers, N. M. J. A., 1977. The ecology of an anuran community. Ph.D. dissertation, University of Sydney, Sydney. 246 Pp.

Dixon, J. R. and Heyer, W. R., 1968. Anuran succession in a temporary pond in New Mexico. *Bull. S. Calif. Acad. ci.* **67:** 129–37.

Greer, A. E., 1994. Faunal Impact Statement for Proposed Development Works at the Homebush Bay Brick Pit. Prepared for Property Services Group.

Heyer, W. R., 1974. Studies in larval amphibian habitat partitioning. *Smithsonian Contrib. Zool. No.* **242:** 1–27.

Homebush Bay Corporation, 1994. Homebush Bay Area Masterplan Synopsis August 1994. Produced by Homebush Bay Corporation: Sydney.

Humphries, R. B., 1979. Dynamics of a Breeding Frog Community. Ph.D. dissertation, Australian National University, Canberra. 217 Pp.

Lemckert, F. L., 1991. Aspects of the reproductive biology and population dynamics of the Common Eastern Froglet, *Ranidella signifera*. Unpublished M.Sc. thesis, University of Sydney, Sydney.

Murphy, M. J., 1996. A capture/recapture study of the endangered hylid frog *Litoria aurea*. *Herpetofauna* **25:** 19–21.

Odendaal, F. J., 1981. The role of the environment and interspecific interaction in determining the distribution of two frog species. Unpublished Ph.D. thesis, Flinders University of South Australia, Adelaide.

Pechman, J. H. K, Scott, D. E., Semlitsch, R. D., Caldwell, J. P., Vitt, L. J. and Gibbons, J. W., 1991. Declining amphibian populations: The problem of separating human impacts from natural fluctuations. *Science* **253:** 892–95.

Pyke, G. H., 1995. Fauna Impact Statement for proposed development works at The Homebush Bay Development Area, excluding the Brickpit. Prepared for Olympic Co-ordination Agency.

Pyke, G. H. and Osborne, W. S. (eds), 1996. *The Green and Golden Bell Frog* Litoria aurea: *Biology and Conservation*. Special edition of the *Aust. Zool.* **30:** 1–258.

Pyke, G. H. and White, A. W., 1996. Habitat requirements for the Green and Golden Bell Frog *Litoria aurea* Anura: Hylidae. In *The Green and Golden Bell Frog* Litoria aurea: *Biology and Conservation* ed by G. H. Pyke and W. S. Osborne. *Aust. Zool.* **30:** 224–32.

Van de Mortel, T. and Goldingay, R., 1998. Population assessment of the endangered Green and Golden Bell Frog *Litoria aurea* at Port Kembla, New South Wales. *Aust. Zool.* **30:** 398–404.

Van de Mortel, T. F. and Buttemer, W. A., 1998. Avoidance of ultraviolet-B radiation in frogs and tadpoles of the species *Litoria aurea*, *L. dentata* and *L. peronii*. *Proc. Linn. Soc. NSW* **119:** 173–79.

Van de Mortel, T., Buttemer, W., Hoffman, P., Hays, J. and Blaustein, A., (in press). A comparison of photolyase activity in three Australian tree frogs. *Oecologia*.

White, A. W., 1993. Ecological and behavioural observations on populations of the toadlets *Pseudophryne coriacea* and *Pseudophryne bibroni* on the Central Coast of New South Wales. Pp. 139–50 in *Herpetology in Australia: a diverse discipline* ed by D. Lunney and D. Ayers. Transactions of the Royal Zoological Society of New South Wales: Mosman.

Wiest, J. A., 1982. Anuran succession at temporary ponds in a post oak-savanna region of Texas. *U.S. Fish and Wildl. Res. Rep.* **13:** 39–47.

Right: Golf Pond, Homebush Bay, March 1996. Very little open water remains as *Azolla* and *Persicaria* have become well established.

Below: Lake Domis, Homebush Bay, January 1994. This photograph was taken looking south-east, with the old abattoir buildings in the background. Note, the frog shelter board in the foreground.

Below right: Manure Pond, Homebush Bay, February 1996. Looking north-west, towards Hill Road, Two in-ground, concrete holding tanks are just visible in the background.